Use of small Tokamak GOLEM

.. as a test bed for application of High Temperature superconductors in Fusion Devices

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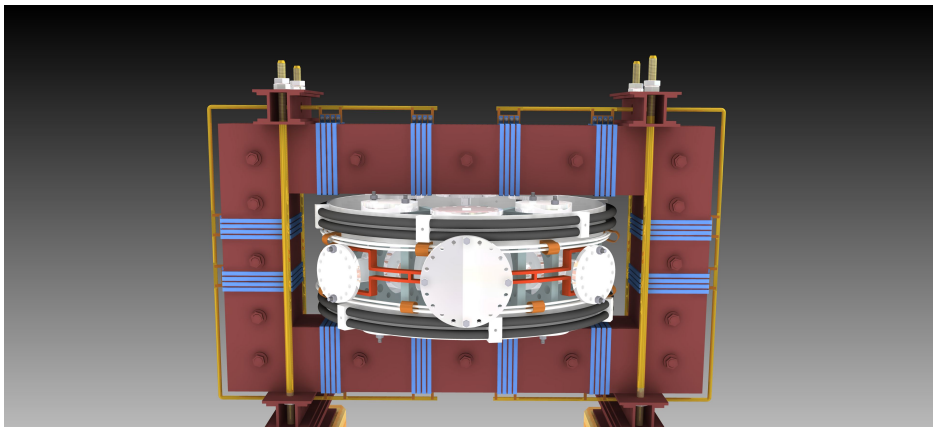


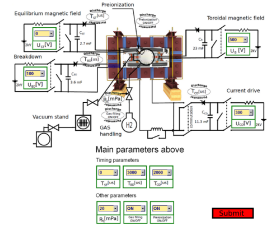
Tokamak GOLEM (for Fusion Education)

internet

Virtual control room (remote participation)

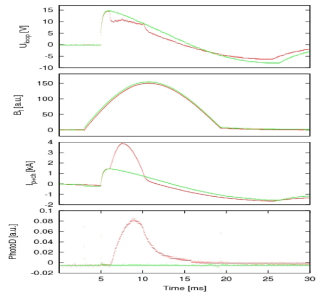
WWW control interface

HTML & PHP scripts



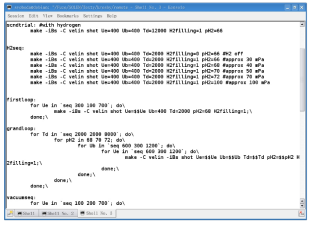
Data presentation

HTML (www pages)



SSH control interface

WINDOWS via putty

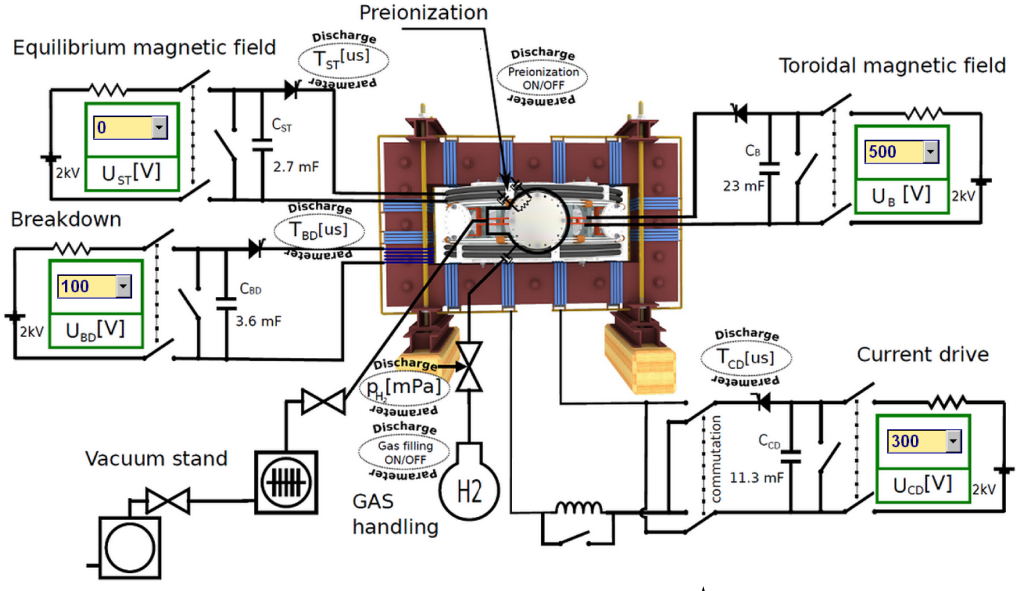


LINUX via ssh
or ssh+X tunnel
(advanced mode)

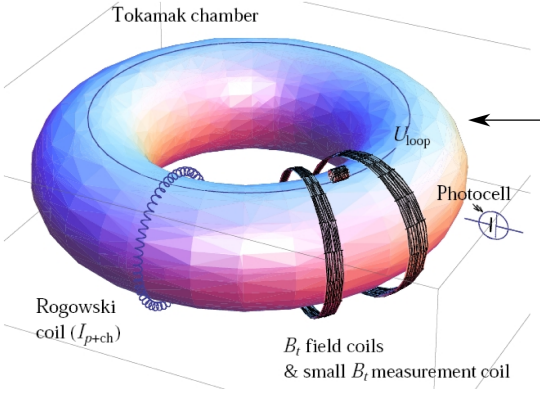
Data handling

*wget
*gnuplot
*idl
*mathematica
*matlab
*etc...

Tokamak control room



Plasma diagnostics



Control PC

OpenSSH server

WWW server
OpenSSH server

Proposed research:

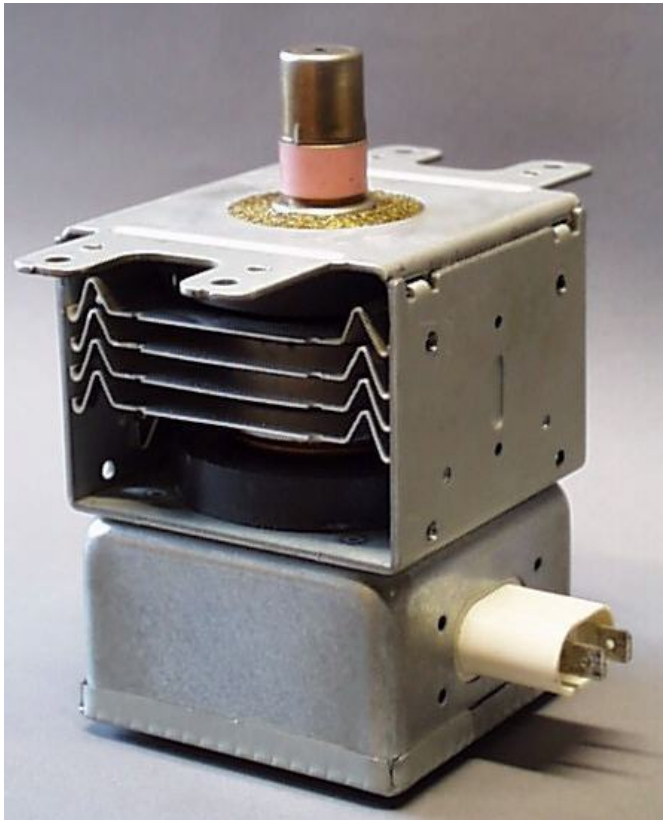
- Tests of HTS magnets and cryostat on GOLEM Tokamak.
- Investigation of performance of HTS magnets during tokamak operations.
- Provide experimental data for the development of new concept of advanced magnets in fusion devices, based on High Temperature Superconductors.
- Studies of properties of HTS in tokamak environment: critical current dependence on magnetic field, temperature, stresses, etc.
- Training of students via participation in operations of the GOLEM tokamak with HTS magnets, participation in IAEA Joint experiments and other education activities.

I. year of the contract

1. Microwave Preionization
2. HTS switch
3. High Temperature Superconductors
4. Education

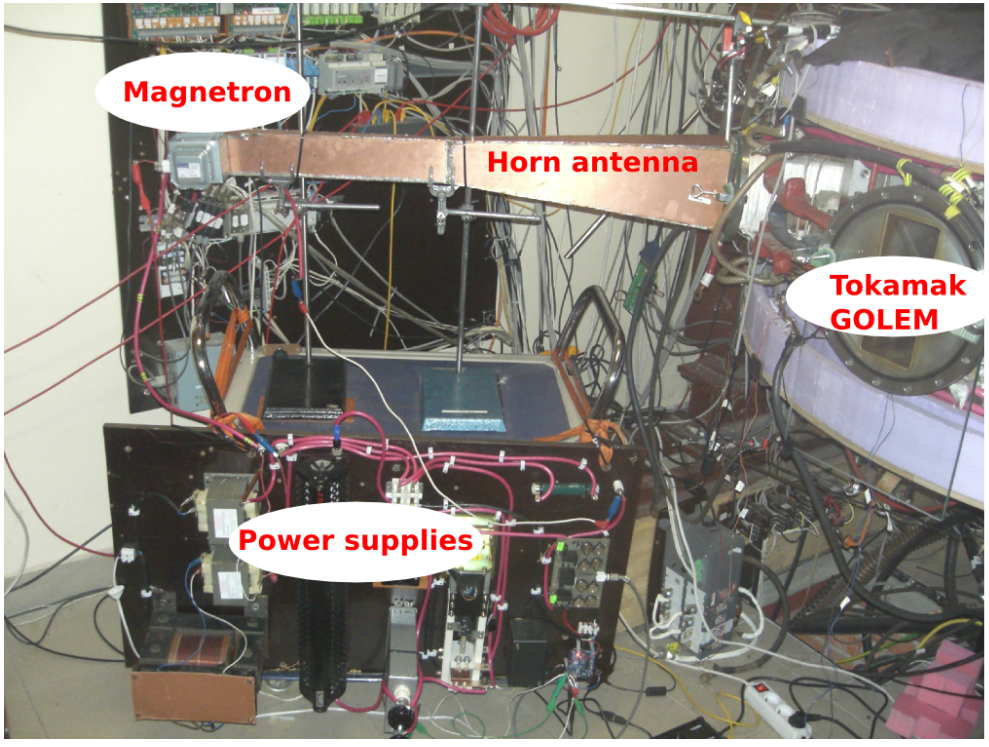
Outline

Motivation



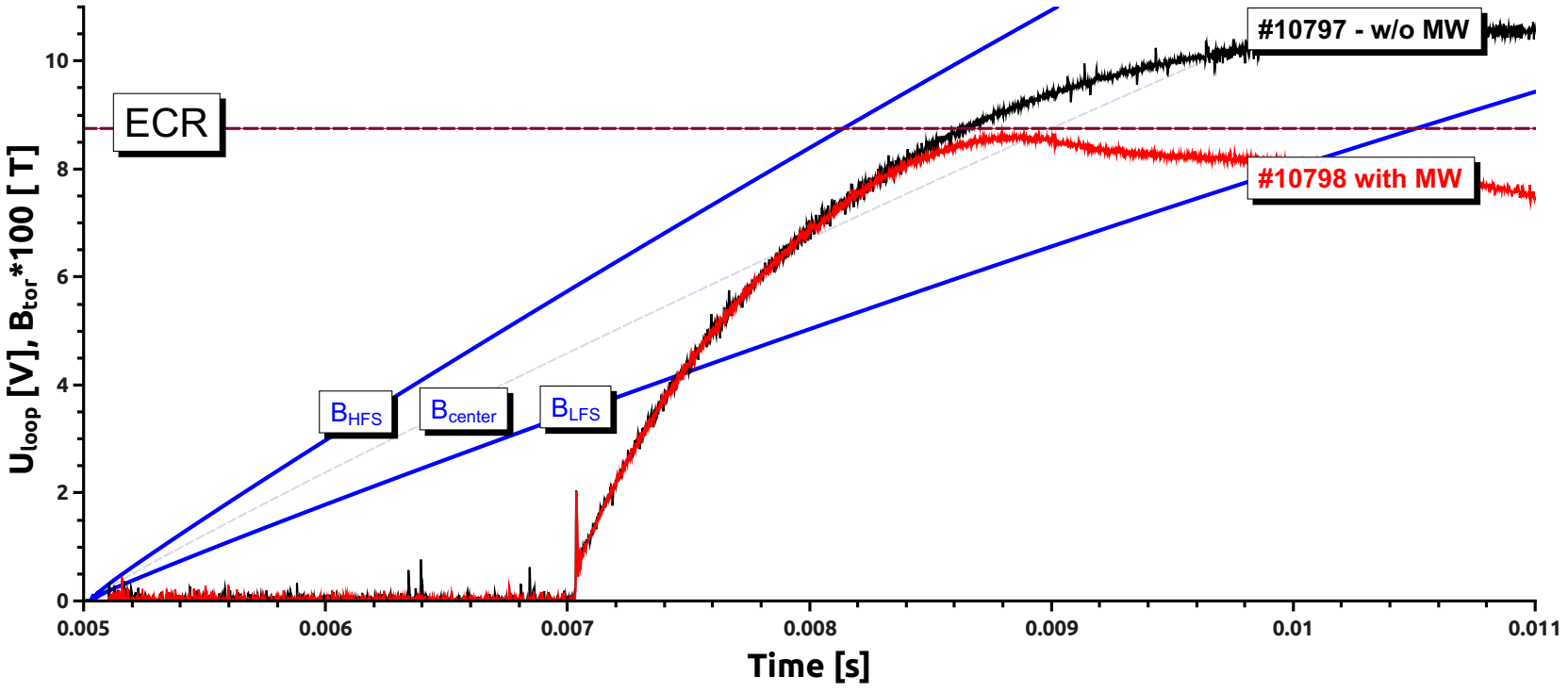
- HTS PF coils application requires modifications to the discharge scenario.
- To reduce AC losses during current ramp-up in HTS coils, reduction in the current ramp-up speed is needed.
- Reduction in the loop voltage needed for the plasma breakdown.
- RF pre-ionization is a powerful tool to achieve this goal.

Experimental arrangement - photo



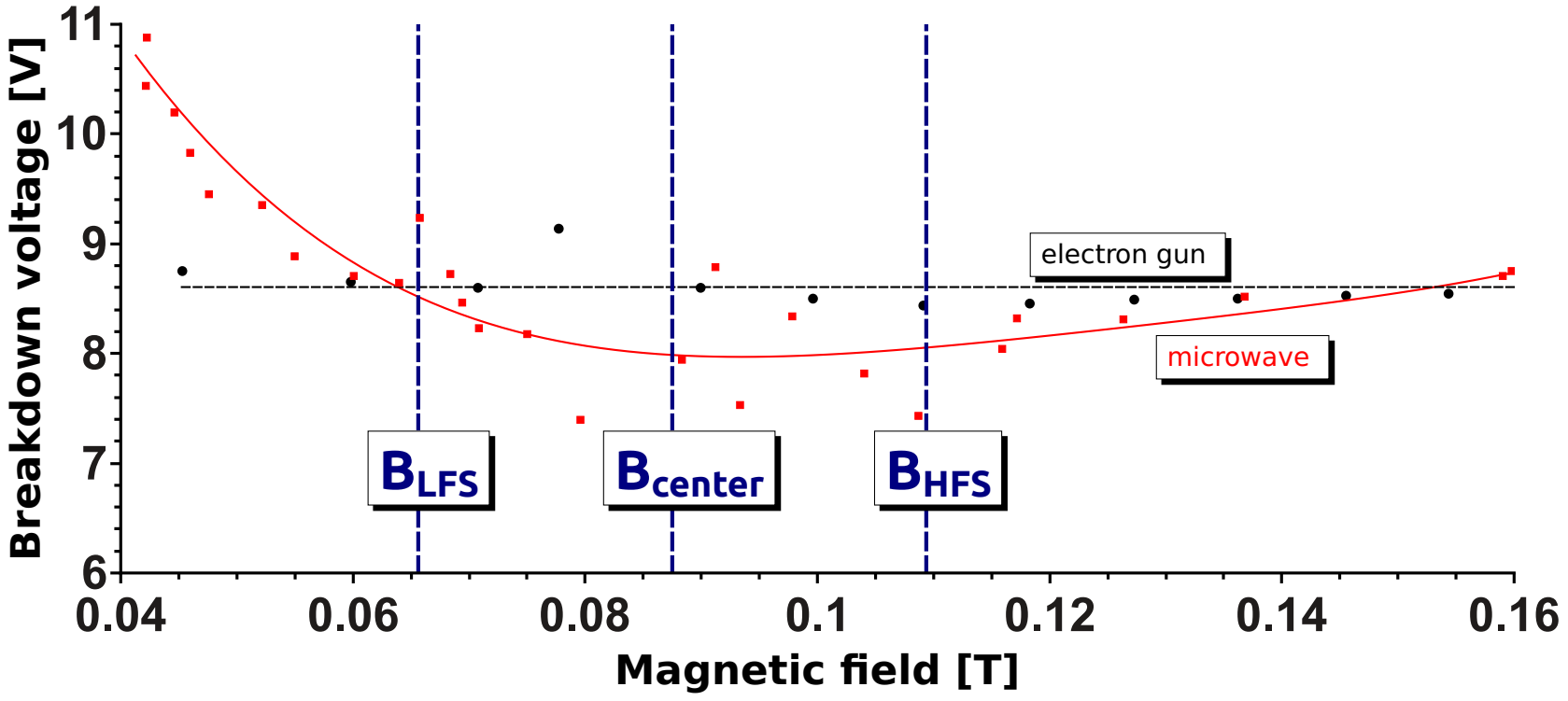
- Magnetron from microwave owen
- Frequency 2.45 GHz
- Output power ≈ 1 kW
- ECR at the magnetic field $B_t = 0.0875$ T.

Microwave breakdown



Breakdown occurs when ECR layer is in the center of the vessel

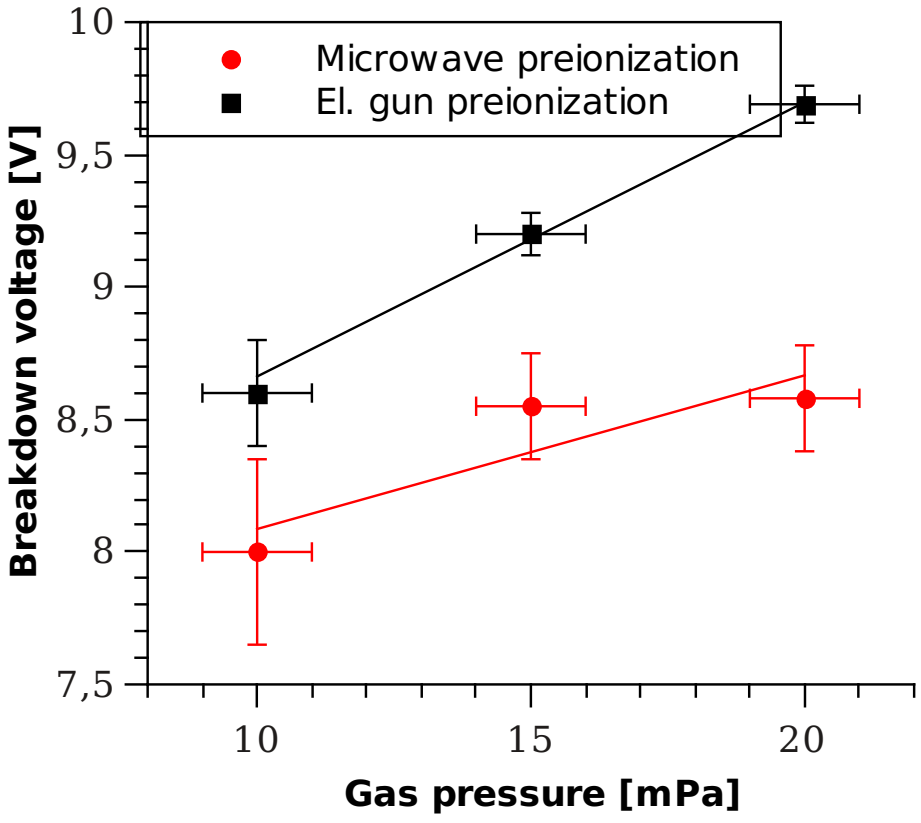
Microwave breakdown @ $p_{H_2} = 10$ mPa



Microwave breakdown:

* is minimum at ECR resonant layer
* appears even without resonant condition (harmonics?)

MW versus Electron gun preionization

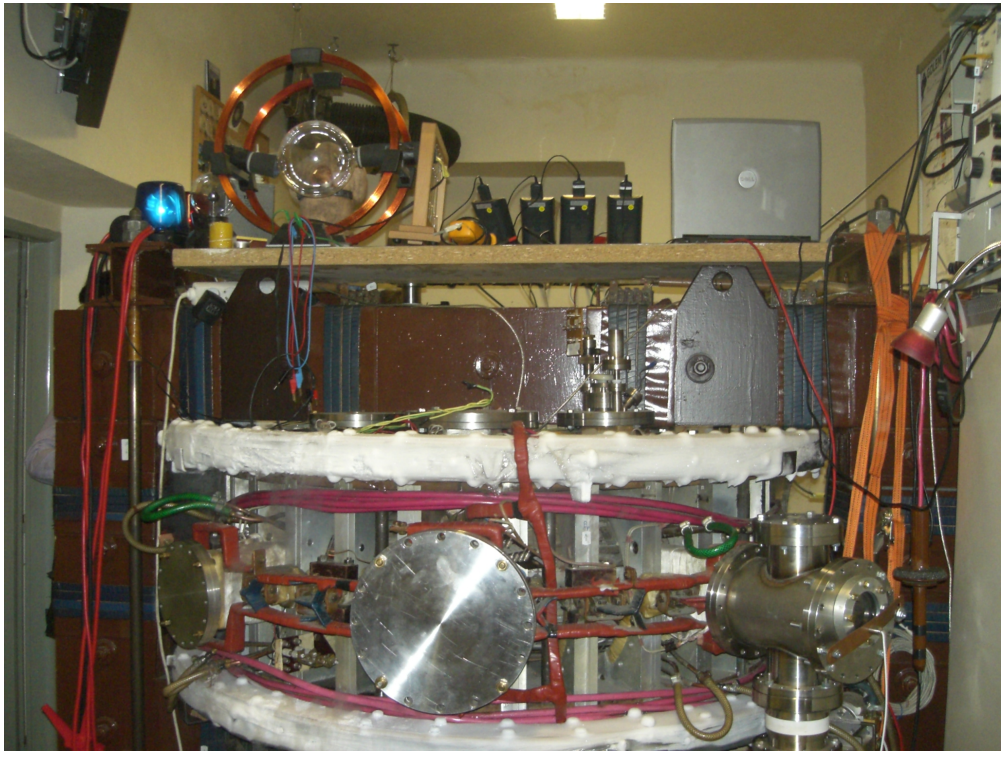


MW preionization

Reduction in the loop voltage achieved for the plasma breakdown

Outline

Motivation

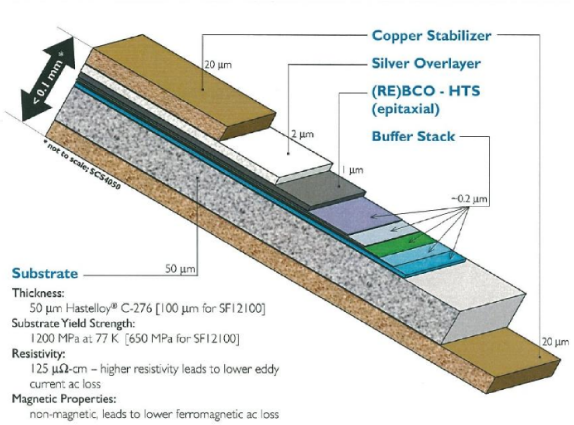


Three types of current drive tested so far with HTS Poloidal field coils on GOLEM:

- DC power supply
- Inductive
- Capacitor discharging

?? How to make superconducting connection ??

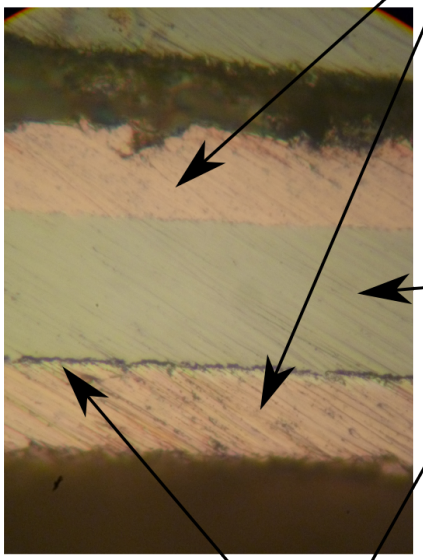
HTS tape under microscope

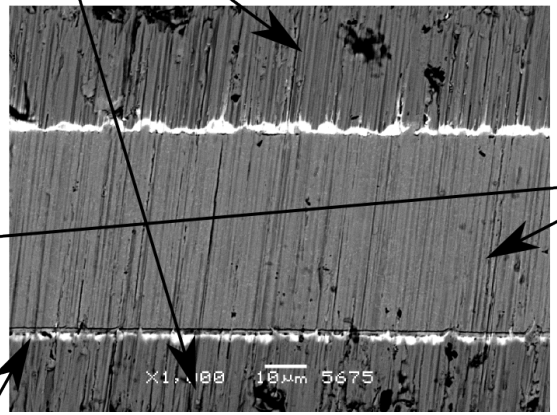


Optical microscope

Electron microscope

Cu

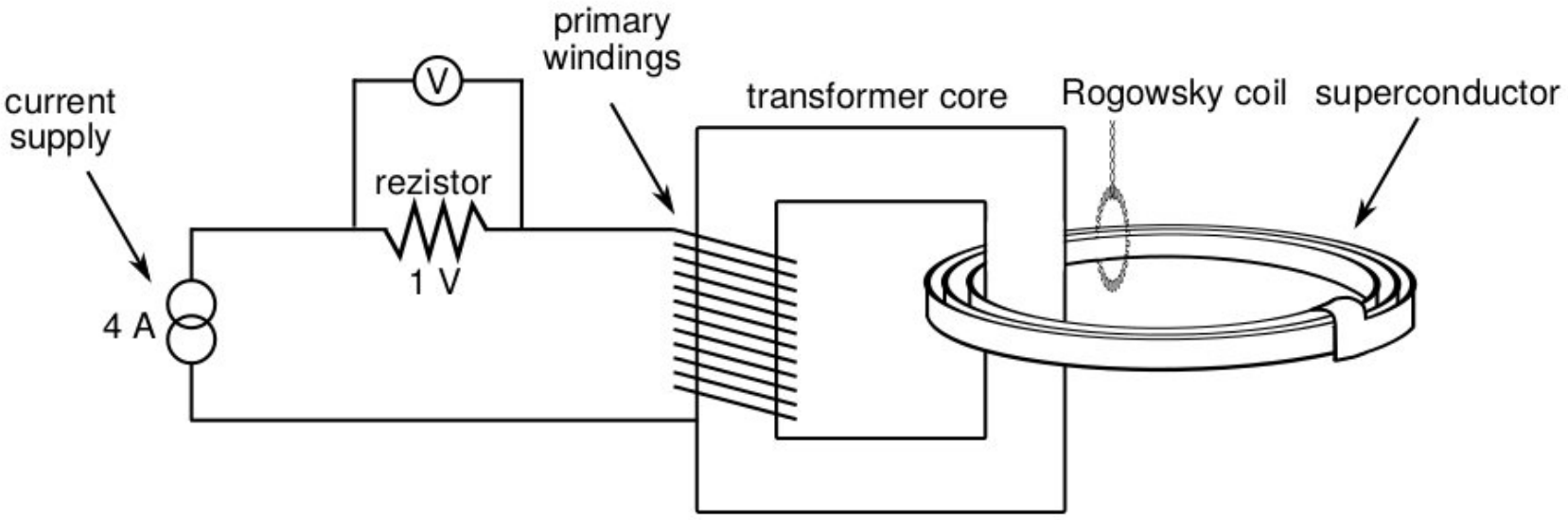




Substrate

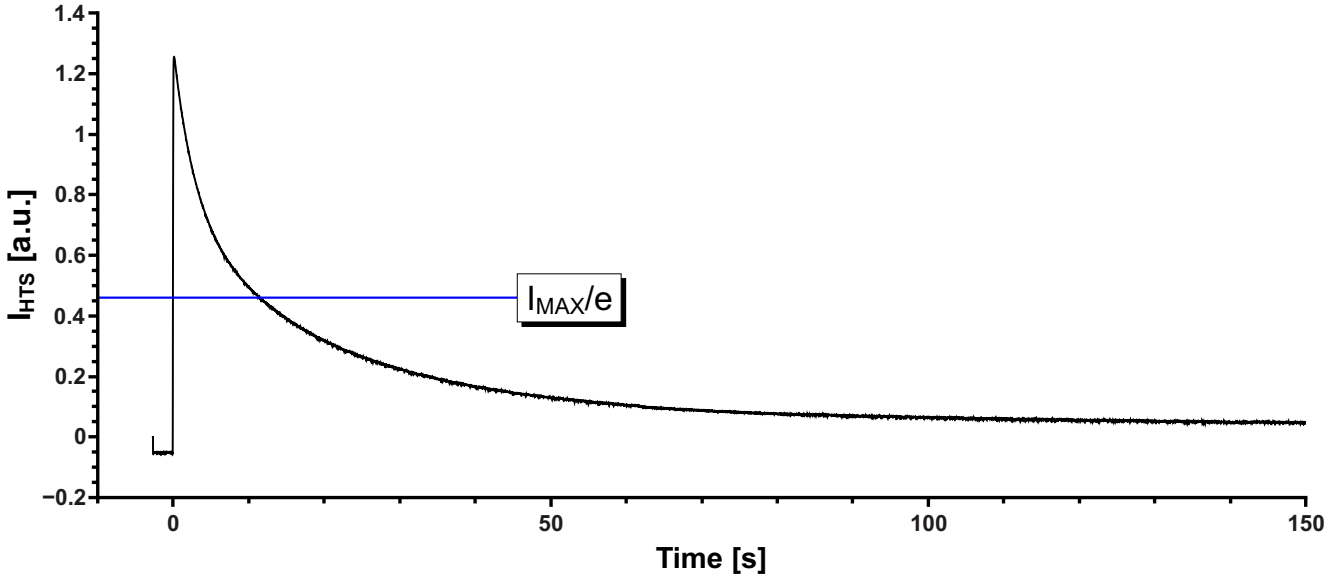
(RE)BCO -HTS

Experimental arrangement - test of HTS soldering



Current is inductively driven in the HTS coil to test quality of soldering

Results

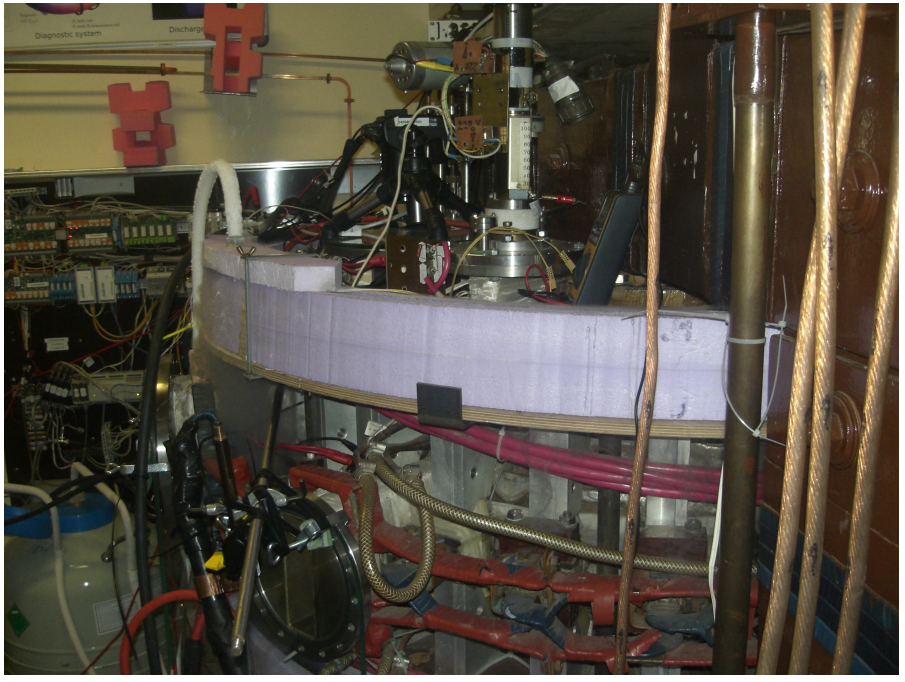


Current decay τ

	amount of tin	side	connection length [mm]	τ [s]
1	large	good	60	10.19
2	large	wrong	60	5.92
3	**small**	**good**	**60**	**11.9**
4	small	wrong	60	5.1
5	small	good	15	1.55

Outline

Introduction

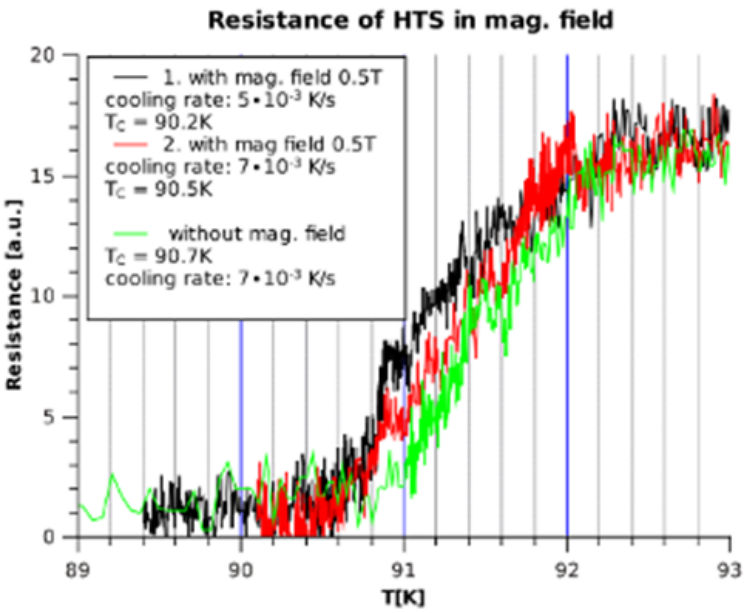


Broad collaboration:

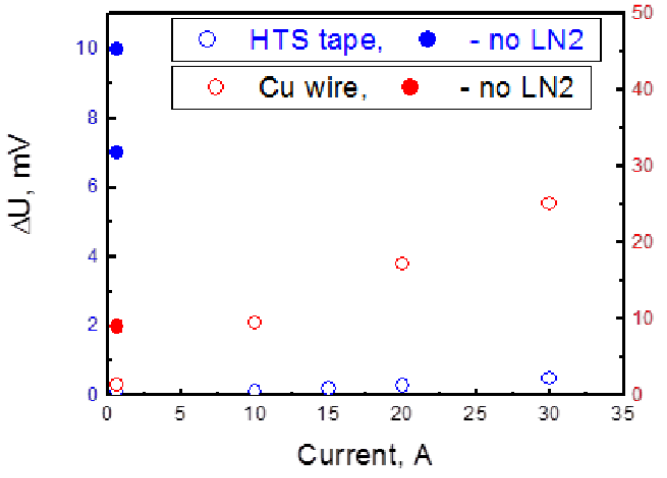
- Tokamak Solutions UK,
- Oxford Instruments UK,
- Czech Technical University in Prague, CR,
- Institute of Plasma Physics, CR

* August September 2011: I. version
* March 2012: Upgrade (better cryostat - LN management improved)

Bench tests

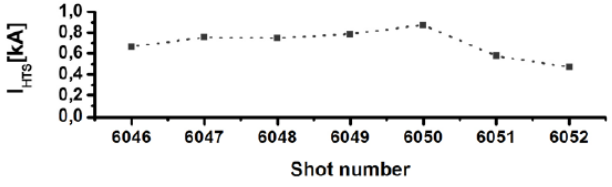


Resistance of a HTS sample vs temperature at different external field and cooling speed.

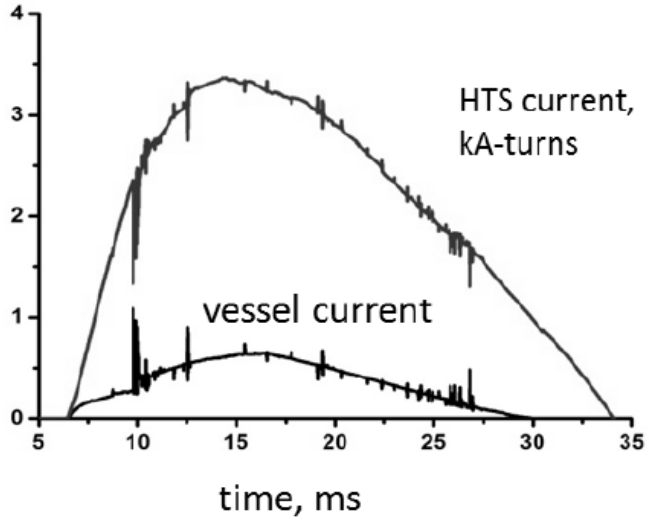


Voltage drop on HTS (blue) and Cu wire (red) vs current at LN2 and room temperatures.

Maximum current and quench studies during pulsed operations

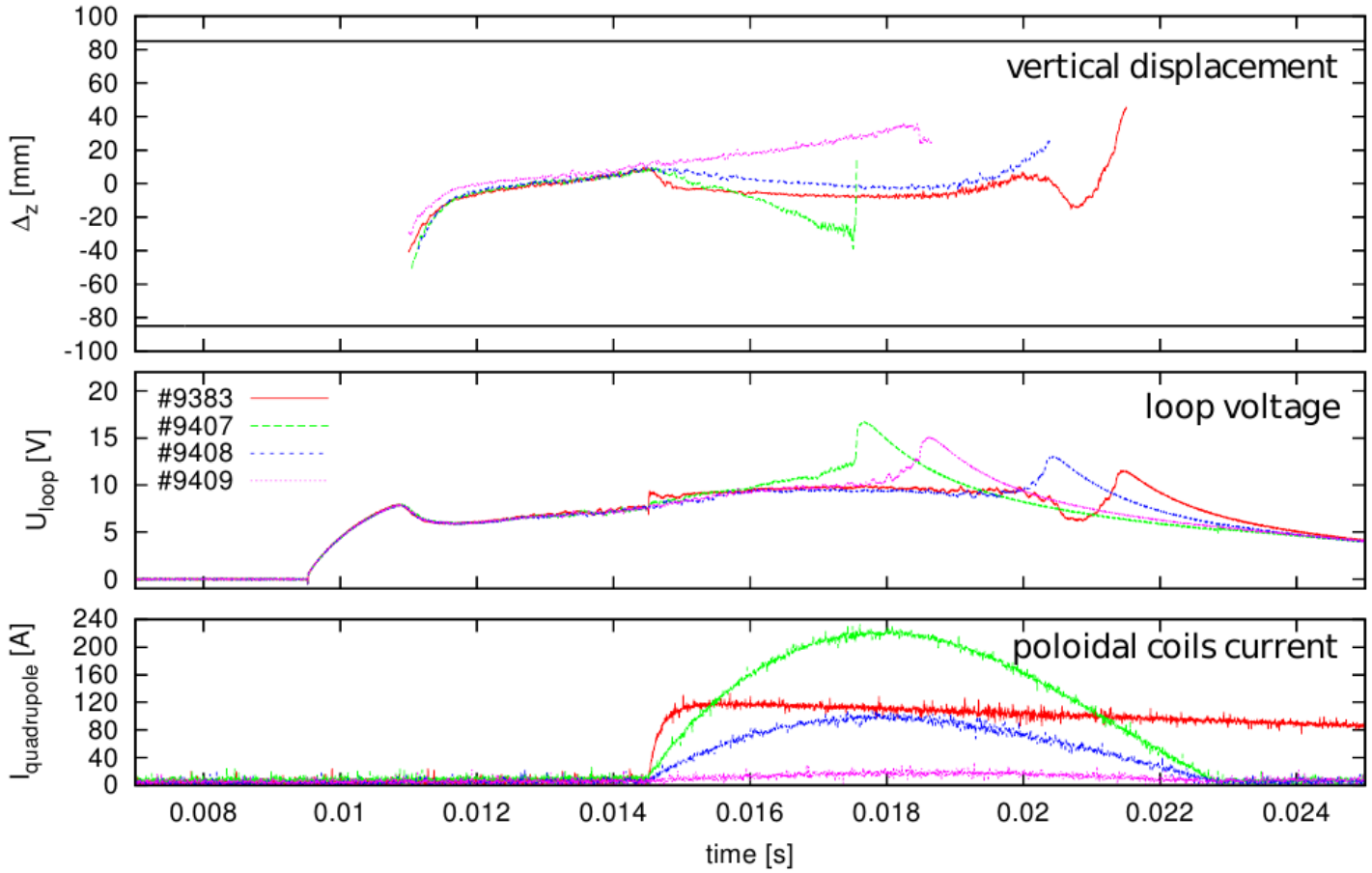


Maximum current in the upper HTS coil in a sequence of pulses.



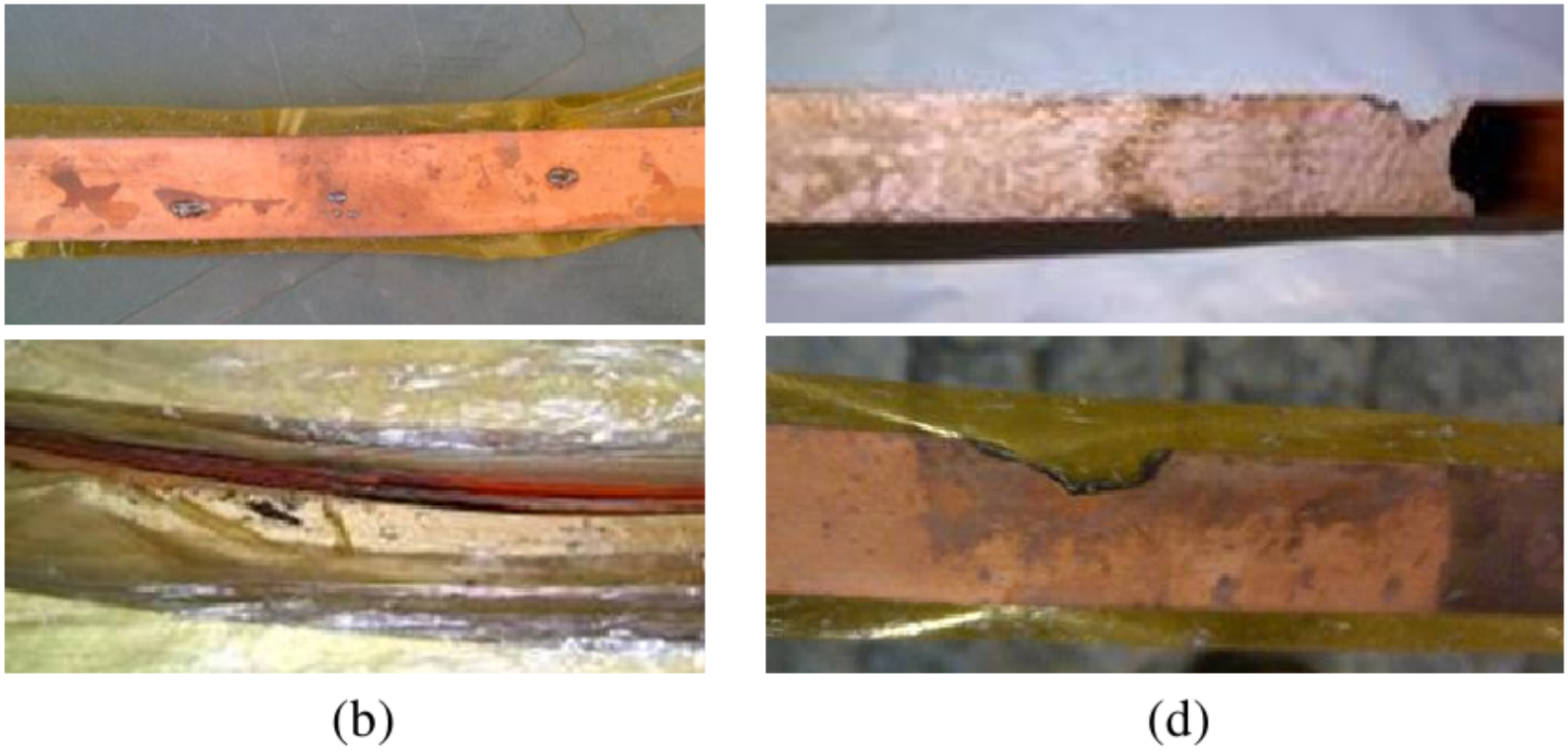
Current in HTS coils and vacuum vessel, pulse #6047, quenches detected.

Plasma operations on GOLEM with HTS coils



Plasma displacement using HTS coils. In #9407 and #9408 coils were in a superconductive state, whilst #9383 were in non-superconductive state. Discharge #9409 is a reference discharge.

Post campaign analysis of the damage of the tape



Hot spots (a,b) and arc damaged tapes, (c,d)

Outline

Students involved in the project

- Tereza Ruzickova (getting ready for bachelor thesis on HTS)
- Main stream: Ondrej Grover, Tomas Markovic, Michal Odstrcil, Jindrich Kocman
- Support: Jaroslav Krbec, Vojtech Stransky, Katerina Jirakova, Ondrej Vrba, Tomas Odstrcil.

Summary

- RF preionization
  - MW driven preionization - reduction in the loop voltage achieved for the plasma breakdown with respect to Electron Gun preionization.
  - To be presented at 40^{th} EPS conference in Espoo.
- HTS switch
  - Current decay $\tau \approx 12$ s achieved in superconducting coil.
  - To be presented at 40^{th} EPS conference in Espoo.
- HTS
  - Bench tests, maximum current and quench studies were conducted on tokamak GOLEM. Plasma operation with HTS coils was demonstrated. Damages of the tape were analyzed.
  - Presented at 39^{th} EPS conference in Stockholm, SOFT Liege and IAEA FEC San Diego.

Publications:

Fusion Engineering and Design, Nuclear Fusion "in pipeline".

Presentations/publications I

The GOLEM team.
Recent results from GOLEM tokamak. 'Indeed, you can teach an old dog some new tricks. .
In *39th EPS Conference on Plasma Physics, Stockholm*, 2012.

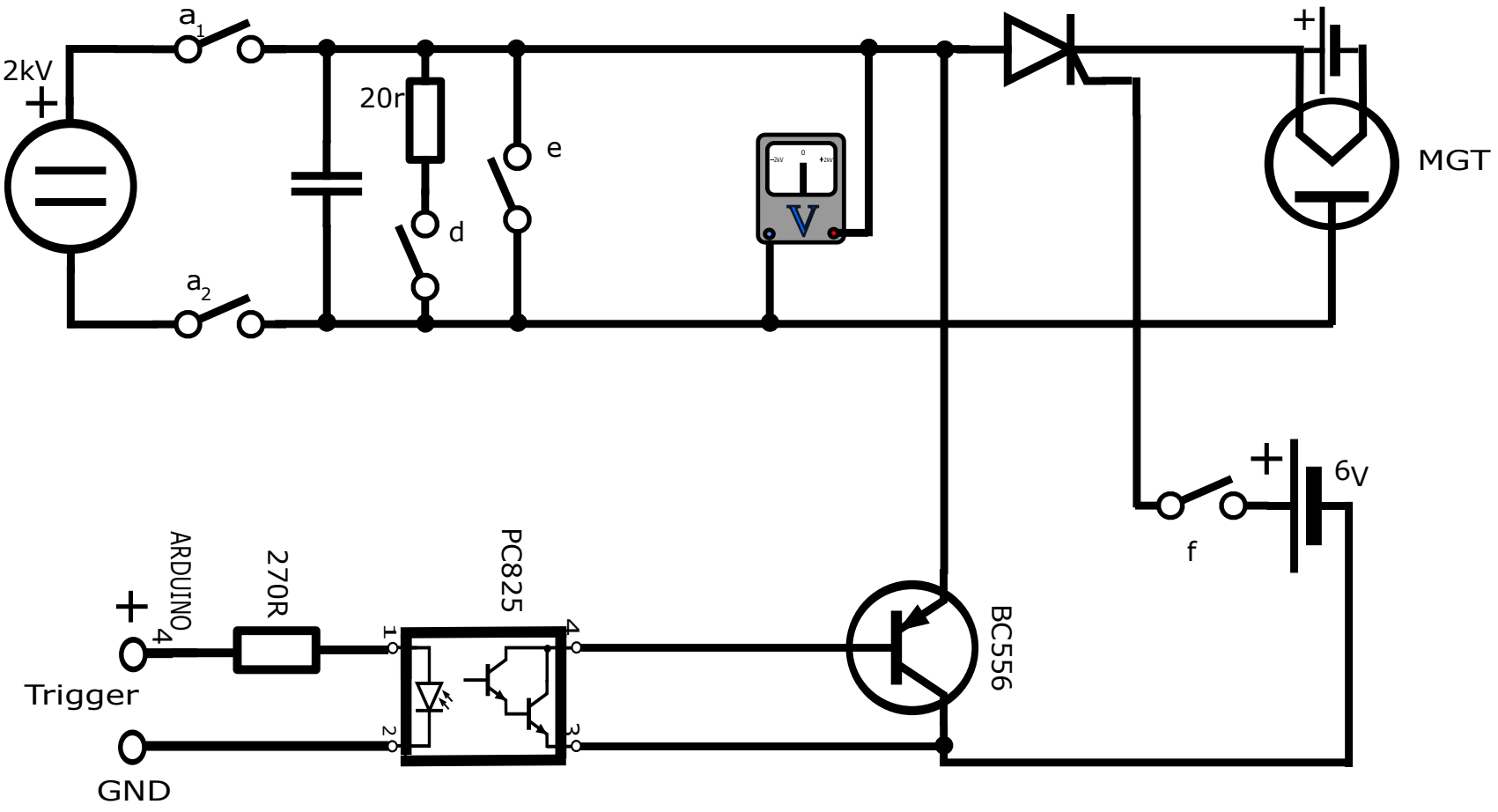
The GOLEM team.
The GOLEM Tokamak for Fusion Education .
In *38th EPS Conference on Plasma Physics, Strasbourg*, 2011.

M Gryaznevich, V Svoboda, J Stockel, A Sykes, N Sykes, D Kingham, T N Todd, S Ball, S Chappell, Z Melhem, I uran, K Kovarik, O Grover, T Markovic, M Odstrcil, T Odstrcil, A Sindlery, G Vondrasek, J Kocman, M Lilley, and H Kim.
Progress in application of High Temperature Superconductor in Tokamak Magnets.
Fusion Engineering and Design (to be published), ():, 2013.

Thanks

Thank you for your attention ..

Electrical Scheme



Experimental arrangement - photo